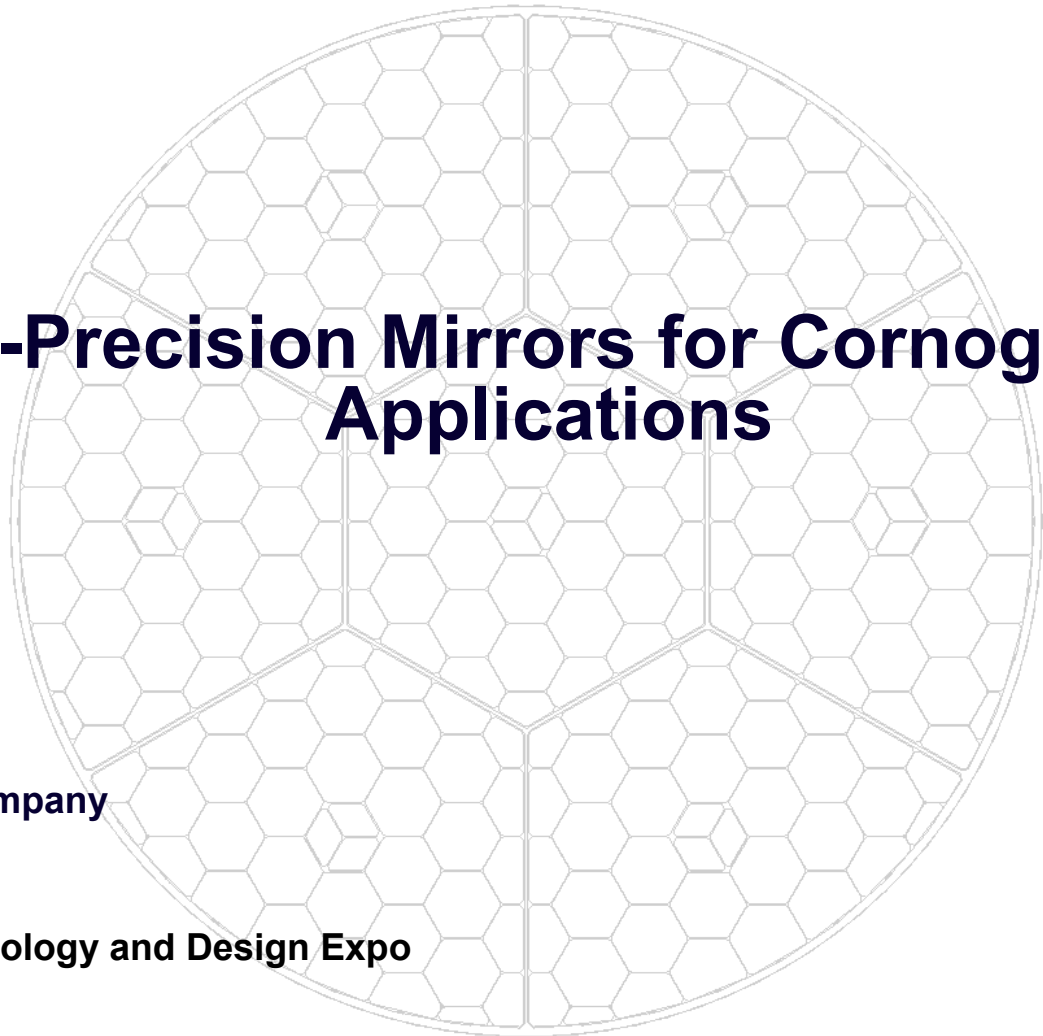
TAKE PICTURES.
FURTHER.



High-Precision Mirrors for Cornographic Applications

Frank Giglio
Eastman Kodak Company
Oct. 15, 2003

TPF Science, Technology and Design Expo

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FURTHER.

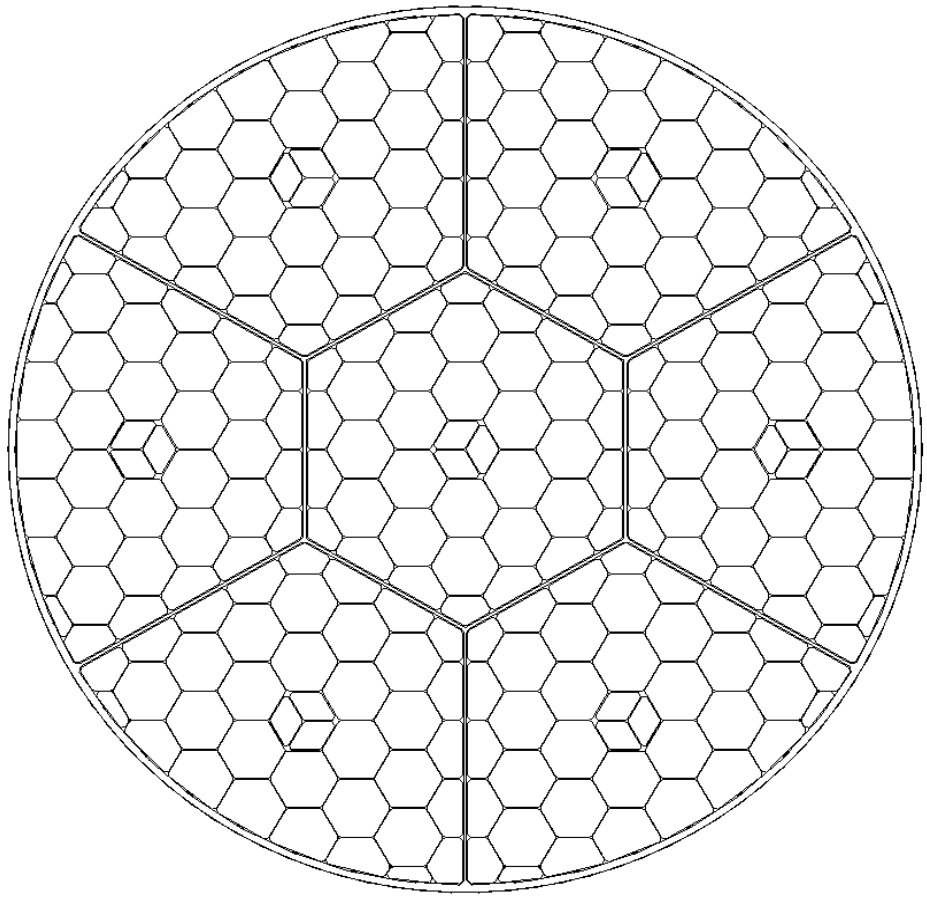
Program Objectives

- **Technology Demonstration Mirror (TDM)**
  - Demonstrate that a large, lightweight, space-qualifiable mirror can be finished and coated to achieve the type of mid-spatial performance needed for a coronagraphic TPF
  - Demonstrate that this mirror's surface can be measured to within the accuracy needed for a coronagraphic TPF
  - Demonstrate that this mirror will maintain its performance through mounting, transportation, handling, launch, and operation
- **Large Monolithic Mirror (LMM)**
  - Develop Mirror Concept for TPF Mission
  - Perform first-order risk-reduction experiments to demonstrate blank manufacturing feasibility

Kodak's Baseline Mirror Design for TDM

TAKE PICTURES.
FURTHER.

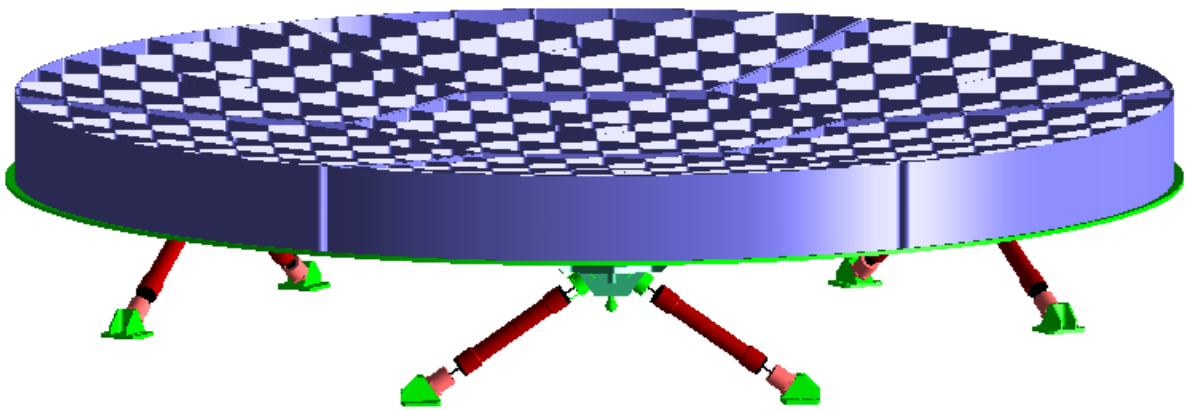
- **A preliminary 1.9 m off-axis mounted mirror design has been completed, which satisfies TDM requirements**
  - Material: Corning ULE® glass gives thermal stability
  - Sandwich Construction: A lightweight honeycomb core sandwiched between front & back faceplates gives structural efficiency (minimizes mirror depth & mass)
  - Segmented Core: Reduces core fabrication risk and cost significantly
  - Low-Temperature Fused (LTF): Gives highly stable all-ULE® construction
  - Low-Temperature Slumped (LTS): Gives efficient near-net shape fabrication and uniform faceplate thicknesses. Processing of components as plano prior to LTS results in reduced cost



TDM Mounting

TAKE PICTURES.
FURTHER.

- **Mounting and testing large, passive mirrors for zero-g applications is not trivial**
- **Kodak has demonstrated a proprietary design to virtually eliminate mount strain**
  - No complex instrumentation required
  - Enables quick integration of PM onto mount struts
  - Readily allows for pre- and post- strut engagement optical testing

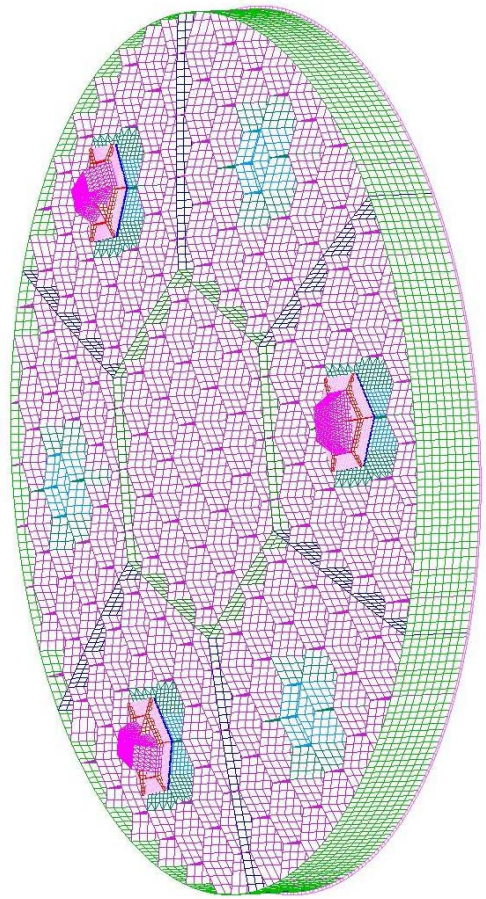


TMD CAD Model
(front plate removed to show core structure)

Predicted TDM Performance

TAKE PICTURES.
FURTHER.

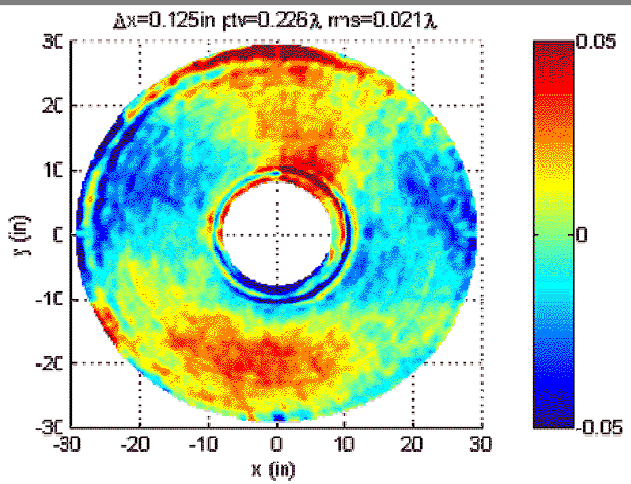
- **Areal density**
  - Including mount: 46.9 kg/m^2 (vs 60 kg/m^2 req.)
  - Mirror alone: 41.9 kg/m^2
- **Stiffness**
  - First free mode: 259 Hz (vs 200 Hz req.)
  - First mounted mode: 87 Hz (vs 85 Hz req.)
- **On-orbit surface figure**
  - Low freq (λ > 40cm): 10 nm rms
  - Mid freq (40cm > λ > 2cm): 4.7 nm rms
  - High freq (2cm > λ > 1mm): 1.4 nm rms
- **Stress margins of safety are positive in all mirror and mount components**



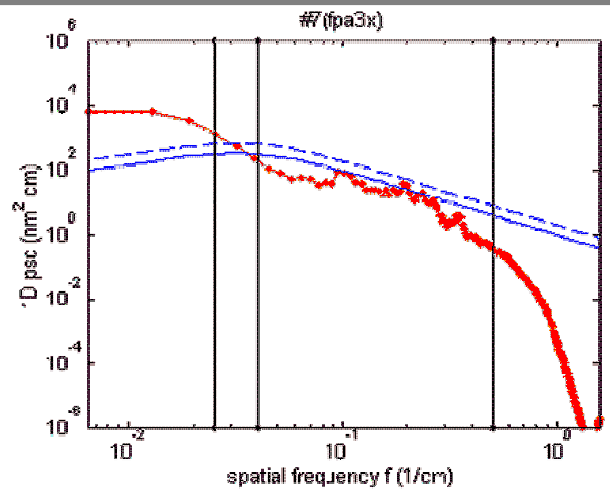
TDM Finite Element Model (back plate removed to show core details)

Existing Kodak Processes Yield Superb Performance in Mid-Spatial Bands

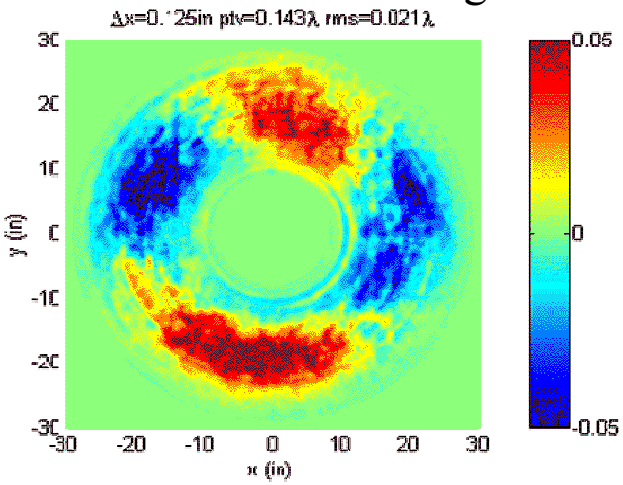
TAKE PICTURES. FURTHER.



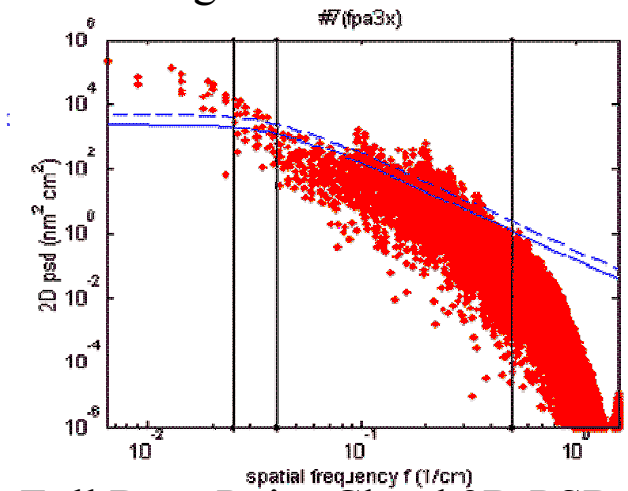
Smoothed Surface Figure



Hanning Windowed Surface Array



Radially Averaged PSD

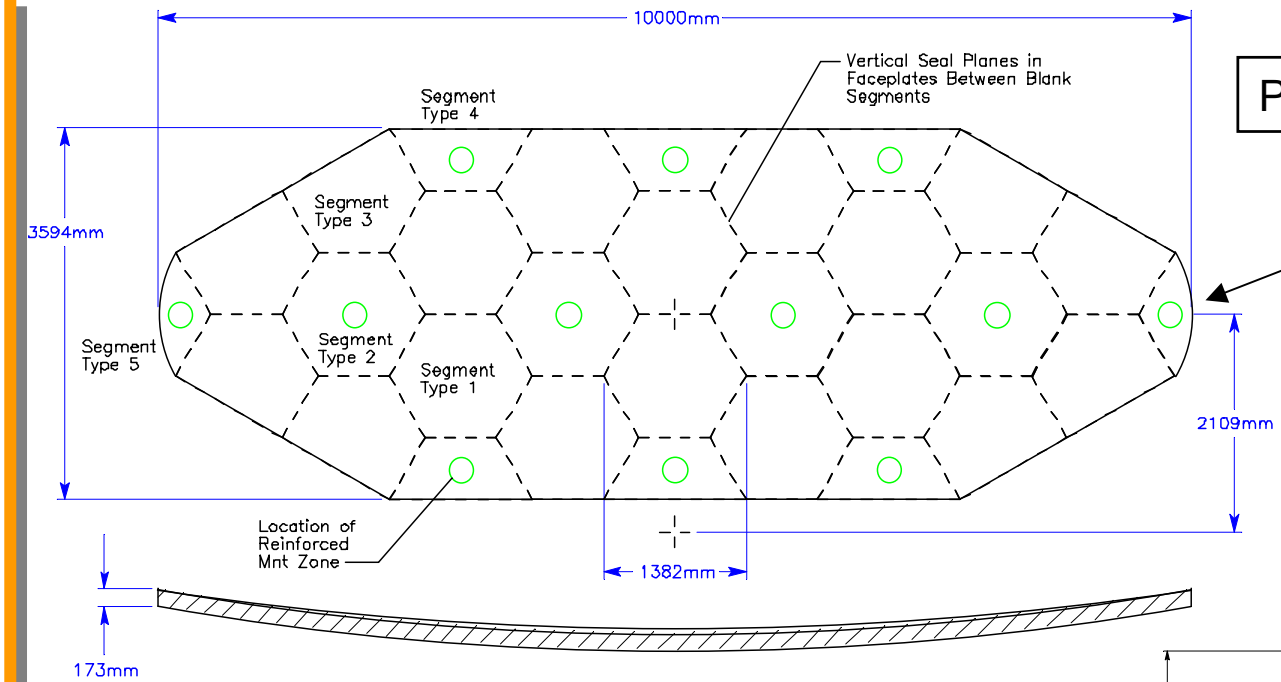


Full Data-Point Cloud 2D PSD Data

Solid blue line on PSD plots is TDM requirement, dashed blue line is not-to-exceed limit.

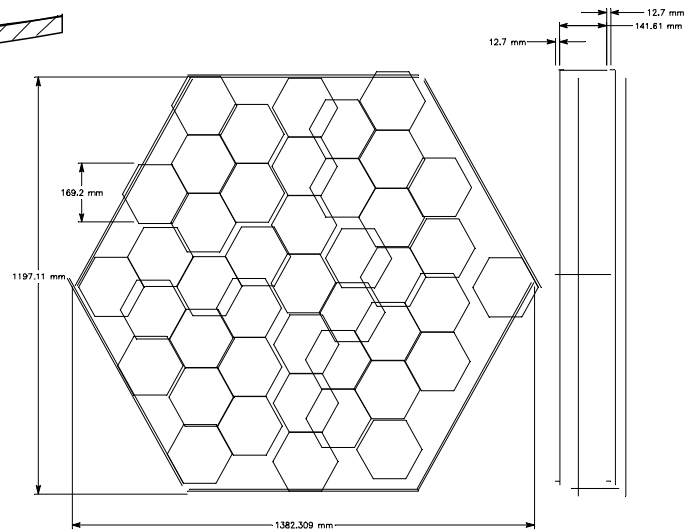
Large Monolithic Mirror for TPF

TAKE PICTURES.
FURTHER.



Proposed LMM blank geometry

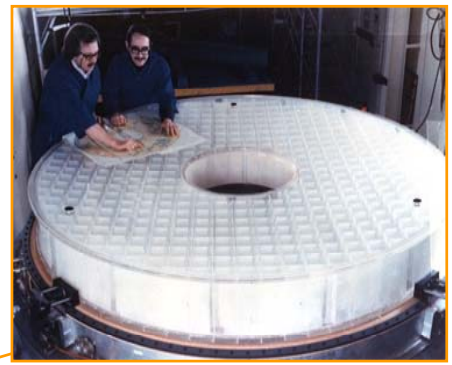
Proposed LTF plano segment blank geometry



- Lightweight design (25 kg/m^2) incorporates pocket-milled plates
- Low-temperature fusion selected for stability
- Edge welding to reduce manufacturing risk
- Low-temperature slumping to produce concave/convex blank

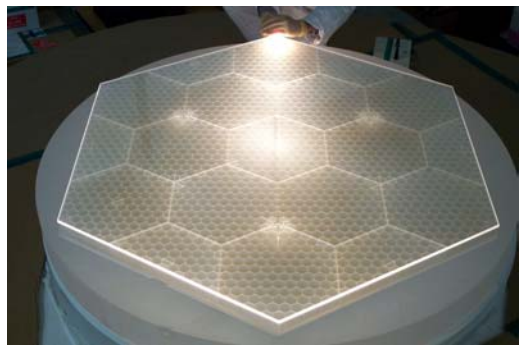
Key Innovations in Lightweight Mirror Technology

TAKE PICTURES.
FURTHER.

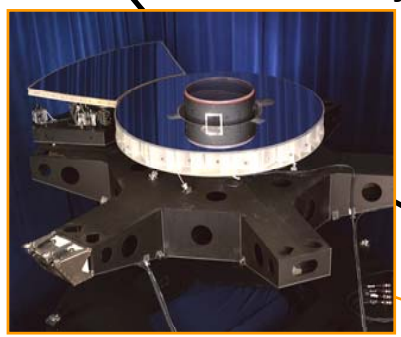


Hubble Space Telescope
BU 2.5 m Primary Mirror

Advanced Demonstrator
0.6 m LTF/Pocket Milled
(scaled to 2.5 m)



AMSD - Class Technology
1.4 m (scaled to 2.5 m)

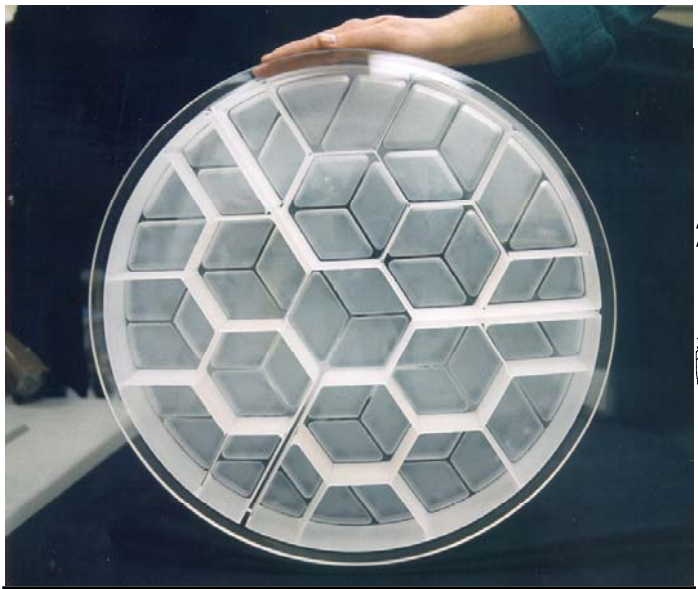


AOSD Telescope
Segmented 2.6 m Primary Mirror

Faceplate Pocket Milling

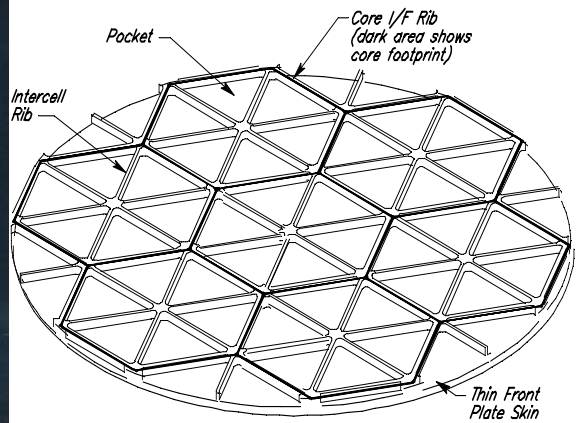
TAKE PICTURES.
FURTHER.

- **Front and back faceplates are pocket milled to reduce mirror mass while maintaining optical performance**



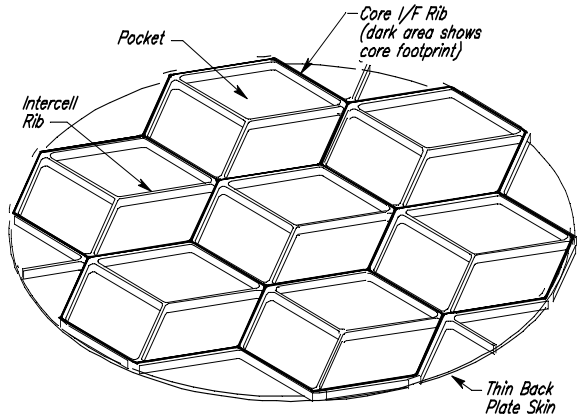
Pocket-Milled Demonstration Mirror (Includes a Segmented Core)

FP Pocket Milling: 6 Ribs Per Cell



Section of Pocket Milled Front Plate (Isometric View)

BP Pocket Milling: 3 Ribs Per Cell

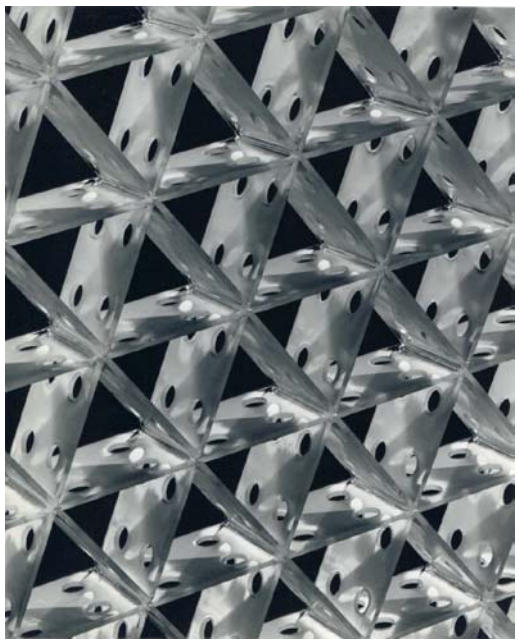


Section of Pocket Milled Back Plate (Isometric View)

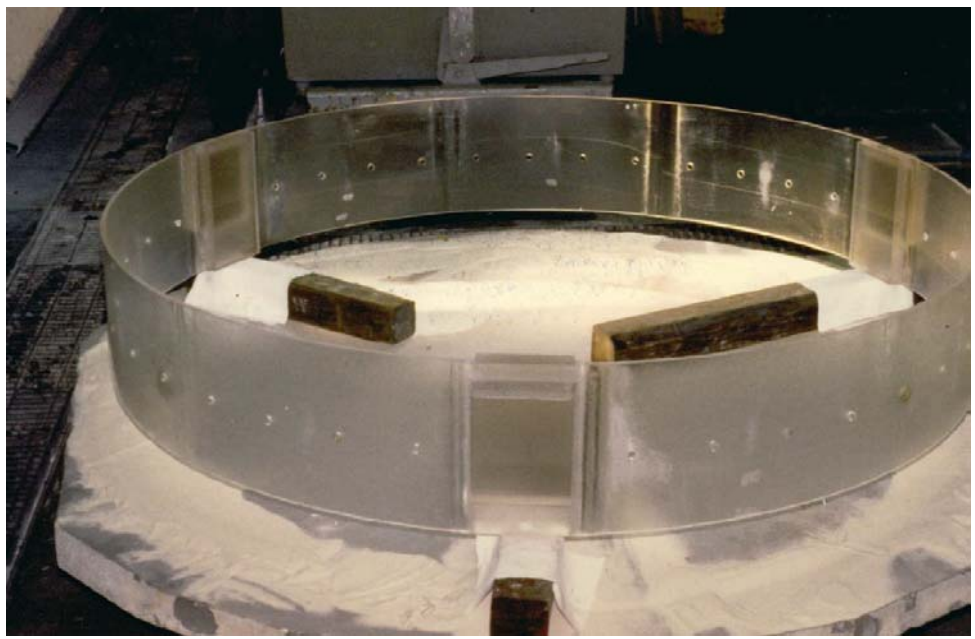
Edge Welding of ULE® Glass

TAKE PICTURES.
FURTHER.

- **Edge welding lightweight ULE® blanks is a key LMM technology**
  - Corning has a long history of welding ULE® glass into various shapes
  - Edge welding lightweight blanks for LMM is an extension of existing methods



Fusion Welded ULE® Mirror Core

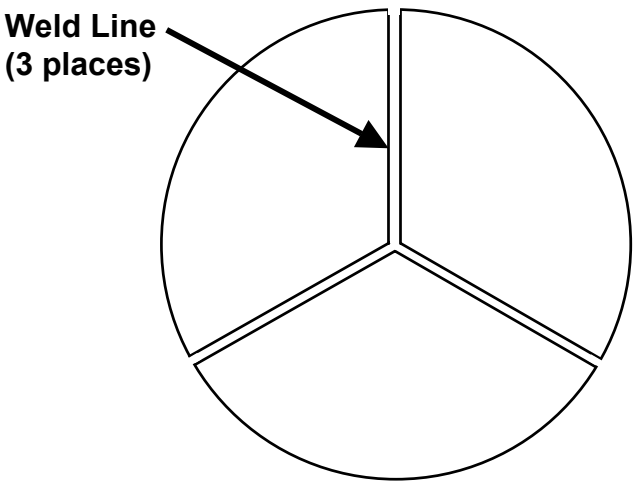


Large-Fusion Welded ULE® Mirror Edge Ring

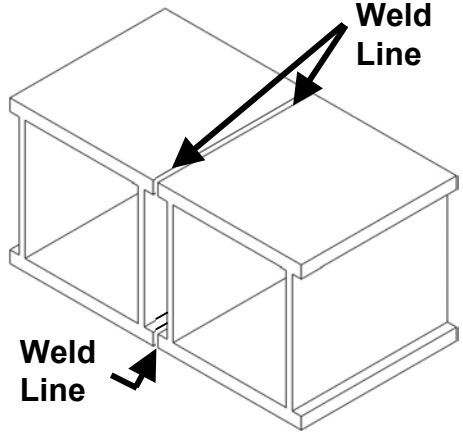
Edge-Welding Demonstrations

TAKE PICTURES.
FURTHER.

- **Corning is fabricating edge-welded test samples for Kodak evaluation under a current NRA study**
  - Samples will be processed at Kodak to evaluate optical finishing across welds and optical performance of seams in welded mirrors



Solid 230 mm Edge-Welded Demo Mirror



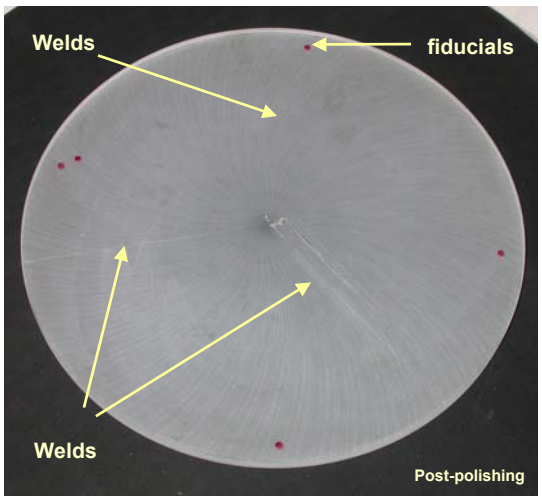
Lightweight Edge-Welded Demo Blank

Edge-Welded Facesheet Blank-Fabrication Results

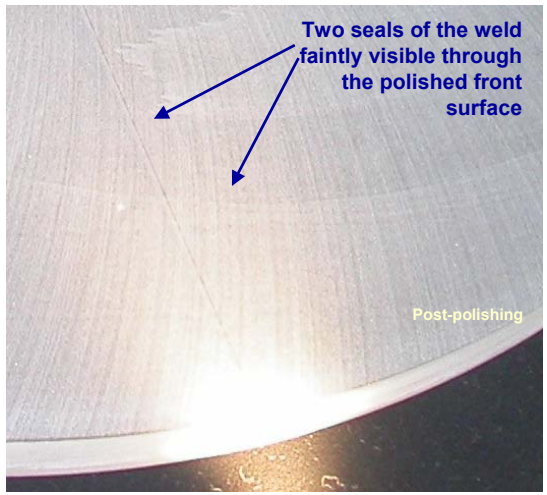
TAKE PICTURES.
FURTHER.

- Corning successfully welded both the facesheet and sandwich blanks

Edge-Welded Facesheet

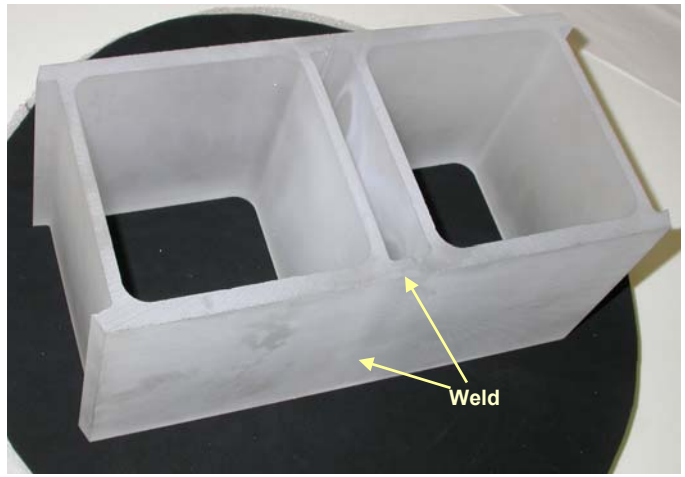


Close-up of weld in the facesheet



Weld

Edge-Welded Sandwich

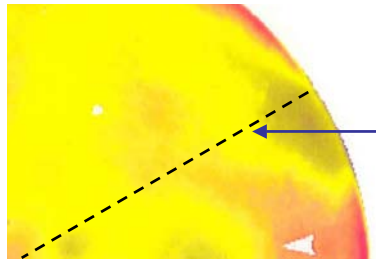


Post-anneal polarimetry indicates zero or extremely low stress in all welds of both the facesheet and sandwich blanks

Edge-Welded Facesheet – Polishing and Testing

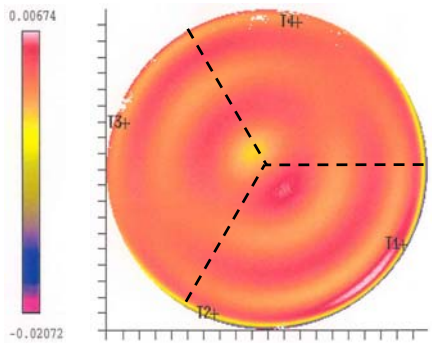
TAKE PICTURES. FURTHER.

- The edge-welded facesheet was successfully polished across the sealed welds with no anomalies or discontinuities



No discontinuity evident across the weld

- The edge-welded facesheet is currently in thermal test at Kodak
  - No local figure change observed at +10°C above ambient: 0.002 λ RMS after removal of lower order zernikes and thermal noise

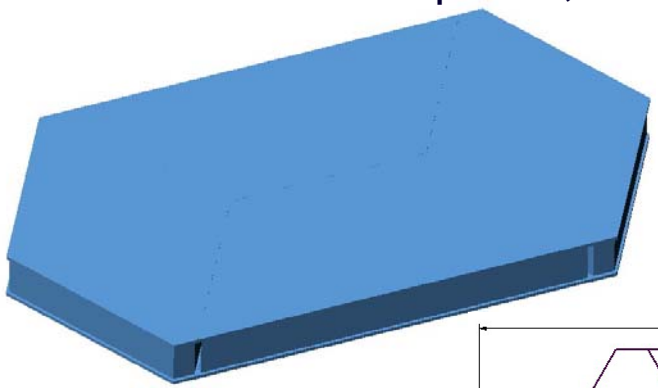


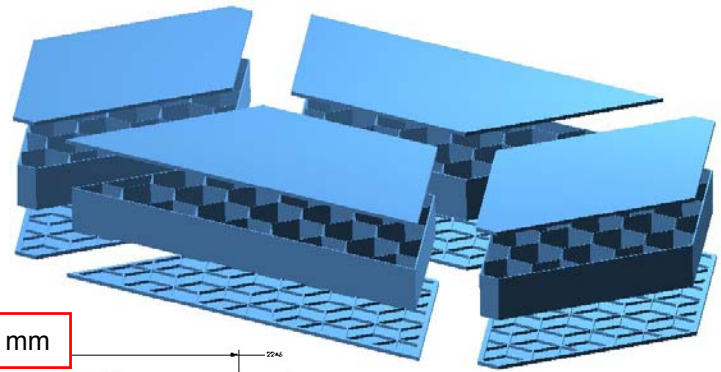
Edge-welded facesheet at elevated temperature reveals no local figure change

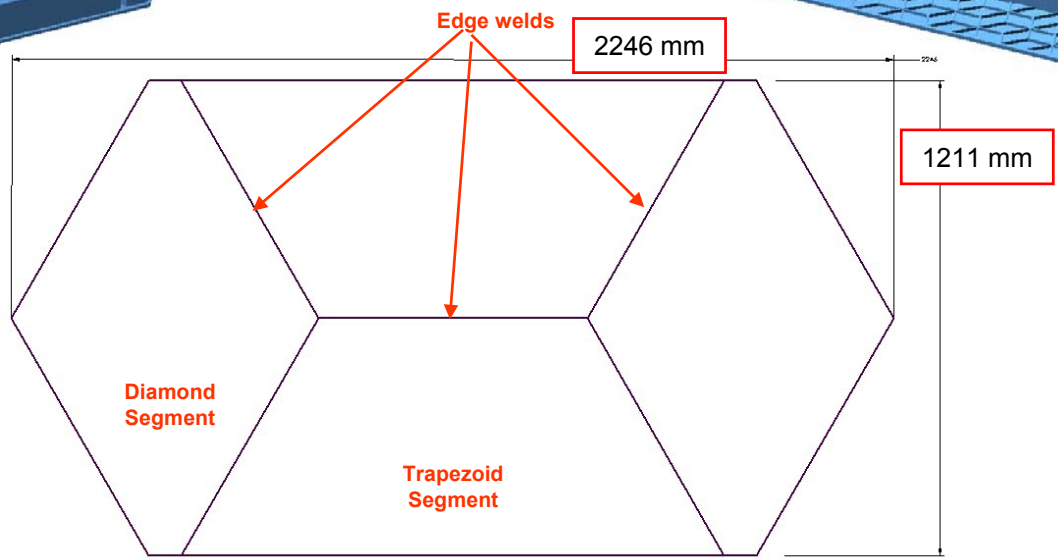
Subscale Demo Mirror Design

TAKE PICTURES.
FURTHER.

- **The subscale demo design maintains the challenges of the full-size mirror, while fitting within existing facilities**
  - Design features include 4 edge-welded segments, pocket-milled front and back plates, and an off-axis asphere







Summary

TAKE PICTURES.
FURTHER.

- **TDM Program will demonstrate ability to fabricate a large optic to quality levels required to enable successful coronagraphic mission**
  - Optical Metrology and Mirror Processing Technologies will demonstrate the ability to address the demanding mid-spatial frequency specifications
  - Low-strain mirror mount approaches will show that it is feasible to develop mount techniques that will maintain the mirror quality and can survive launch
- **LMM has developed a TPF scale mirror concept**
  - Concept requires development of edge welding to assemble multiple segments into a monolithic structure
    - First-order tests validate edge welding feasibility
  - Subscale mirror concept defined to reduce fabrication risk on a larger scale traceable to the LMM design concept